The Aerosol Global Interactions Satellite (AEGIS) concept: Science objectives, mission design considerations, and applications to air quality

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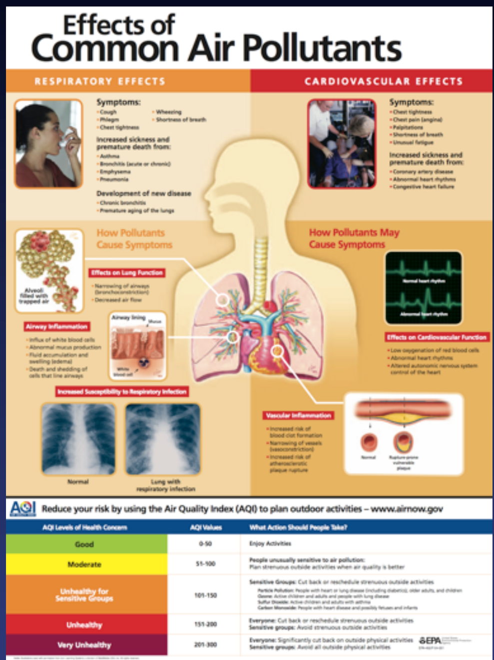
Aerosols affect human and environmental health & welfare



Airborne particulate matter (PM) is linked to a variety of health problems…

- respiratory symptoms: irritation of the airways, coughing, difficulty breathing
- decreased lung function, aggravated asthma, chronic bronchitis
- irregular heartbeat, nonfatal heart attacks
- premature death in people with heart or lung disease (tens of thousands in the US per year)

…and affects human and environmental welfare

- reduced visibility in cities, parks, and wilderness areas
- acidification of lakes and streams
- damage to crops and forests
- long-range transport of disease vectors
- staining and damage to building exteriors and cultural monuments

Scientific and societal goals pertaining to particle pollution

- Identifying principal region-specific local and imported aerosol sources

- Establishing results of human and natural activities (industry, transportation, fuel-use changes, emission controls, forest fires, dust storms, volcanoes) on particulate pollution distributions and trends

- Obtaining inputs to studies of the epidemiological and environmental impacts of severe episodic events and long-term regional exposures

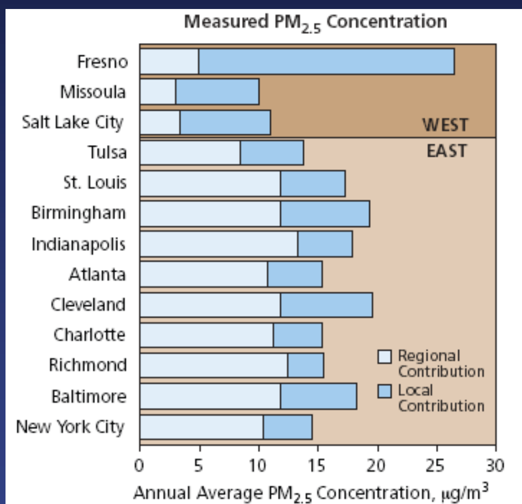
- Providing near-real-time inputs to air quality Decision Support Systems

Relevant spatial scales

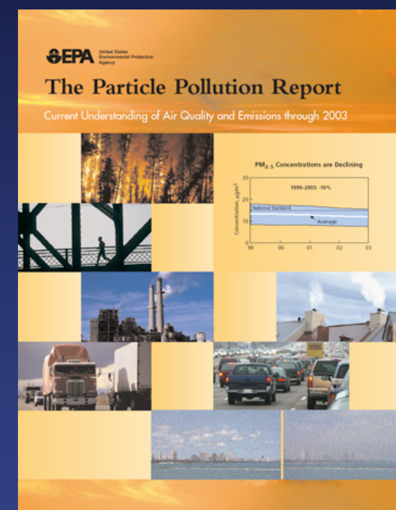
Merits of combining *in situ* and satellite PM monitoring

Annual and 24-hour compliance standards exist in some countries, e.g., the US National Ambient Air Quality Standards (NAAQS)

***In situ* monitors provide critical, direct PM concentration and speciation measurements, but do not tell the whole story:**



- *Although the US EPA operates > 1000 $PM_{2.5}$ monitors, vast rural and suburban areas—where most people tracked in long-term epidemiological studies live—are not covered*
- *In the eastern US, 50-75% of particle pollution is non-local*



In situ challenges and limitations	How satellites contribute
• delays in network deployment and completion	• once deployed, coverage is worldwide
• disputes over how to perform spatial averaging	• spatial sampling is more extensive, more uniform
• difficulty in source attribution for localized data	• aerosol sources and transport are observed
• monitoring is near-surface and over land only	• monitoring includes PM aloft and over water

The vision: A quantitative global PM observing system

Meeting the aforementioned scientific and societal goals requires not only mapping 2-D aerosol patterns, but also to:

- **Use satellite aerosol data in a quantitative 3-D PM observing system. This requires:**
  - minimizing inherent indeterminacies in column optical depth retrieval (parameter covariances and effects of surface background reflectance)
  - accounting for the aerosol vertical distribution
  - having adequate spatial resolution to observe intra-city gradients (1-2 km) and to distinguish aerosols and clouds
  - having adequate temporal sampling to account for aerosol residence times and to validate / initialize air quality models (days)

- **Discriminate aerosol pollution by particle type and determine aerosol influences on radiation fluxes. This requires:**
  - having layer-wise and column-integrated sensitivity to extinction, absorption, and microphysical properties such as particle sizes and shapes
  - measuring compositional proxies, e.g., complex refractive index
  - integrating satellite measurements with surface and airborne data, since aerosol chemistry is not observable from space

The Aerosol Global Interactions Satellite (AEGIS) concept

passive sensor heritage

MISR | MODIS | AATSR | APS | POLDER | TOMS

active sensor heritage

GLAS | CALIPSO

+ Instrument Incubator Program (IIP4) technology developments

ruggedized electro-optic retardance modulators for high-accuracy, self-calibrated polarization imaging

355-nm laser output & receiver channels; scalable frequency-agile laser source suitable for space

Multiangle SpectroPolarimetric Imager

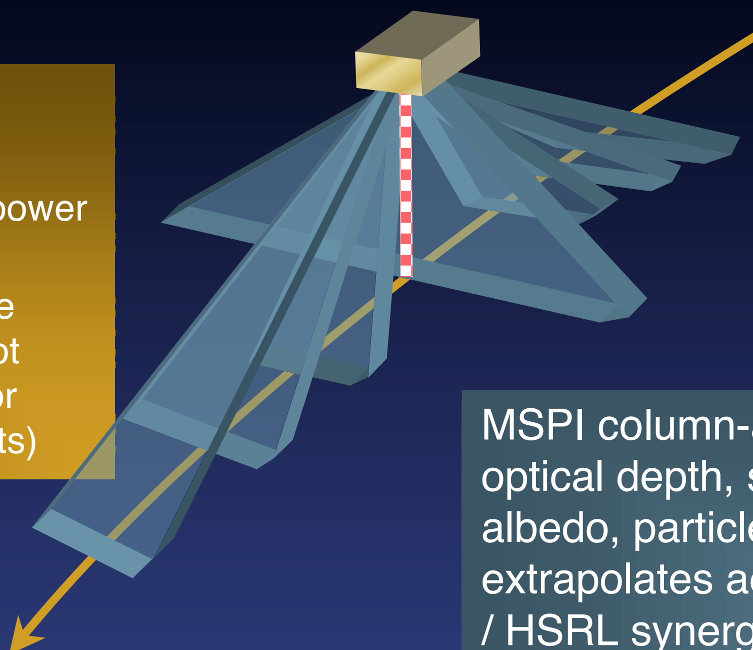
High Spectral Resolution Lidar

Parameter	MSPI	HSRL
View angle range	Nadir to 70°, fore and aft	Nadir
Spectral range	Intensity: 380 - 2130 nm Polarization: 650, 1610 nm (0.5% uncertainty in DOLP)	HSRL: 355, 532 nm Backscatter only: 1064 nm Polarization: all three λ
Spatial resolution of derived aerosol products	Horizontal: 1-2 km Vertical: 200 m for plumes	Horizontal: 20 km Vertical: 120 m (backscatter), 900 m (extinction)
Global coverage time (swath width)	Multiangle: 4 days (700 km) "Nadir": 1 day (2650 km)	NA (100 m)

AEGIS mission strategy

Low Earth orbital altitude (470 km)

- Minimizes HSRL power and mass
- Enables multiangle views by MSPI (not possible from L1 or geostationary orbits)



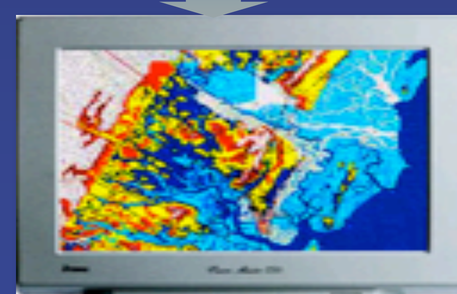
HSRL measures layer-wise profiles of aerosol properties (eff. radius, complex refractive index, shape, concentration), plus column optical depth

- Segregates near-surface and layer aerosol properties from total column

MSPI column-averaged aerosol sensitivity to optical depth, size distribution, single-scattering albedo, particle shape, refractive index extrapolates aerosol models derived from MSPI / HSRL synergy to broad swath

Stereo provides two-dimensional maps of aerosol plume injection and transport heights

Coverage enables integration with surface network, aircraft data, and assimilation models

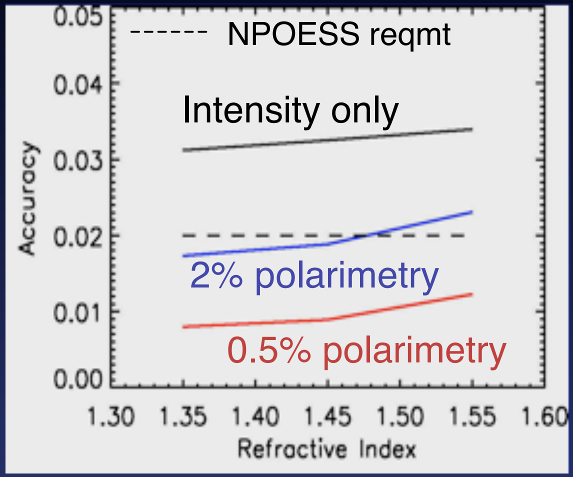


Key MSPI and HSRL developments

Visible, near- and short-wave IR intensities yield particle size and shape, UV data constrain aerosol absorption, and accurate polarimetry is required for real refractive index and particle size variance.

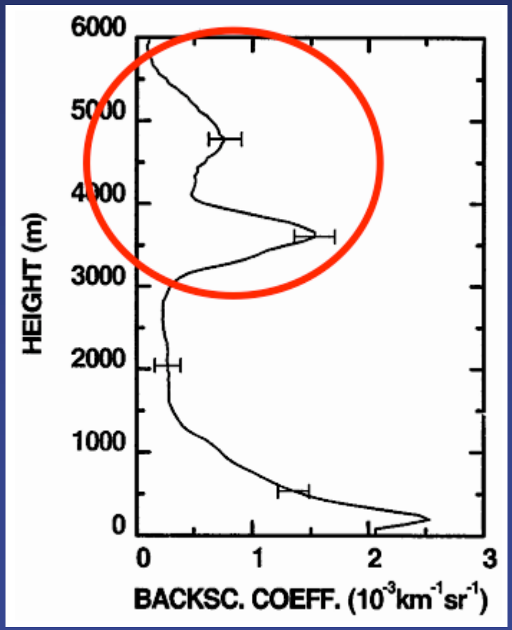
Currently planned UV / polarization sensors (OMPS, APS) do not have high spatial resolution and / or global coverage.

MSPI technology (high-performance optics, photoelastic modulators, and on-board signal processing) makes this feasible. Meeting 0.5% polarization is the biggest challenge.



Conventional backscatter lidars are not capable of profiling aerosol concentration or microphysical parameters and provide only limited information on particle type.

HSRL overcomes these limitations to provide size information and compositional proxies.



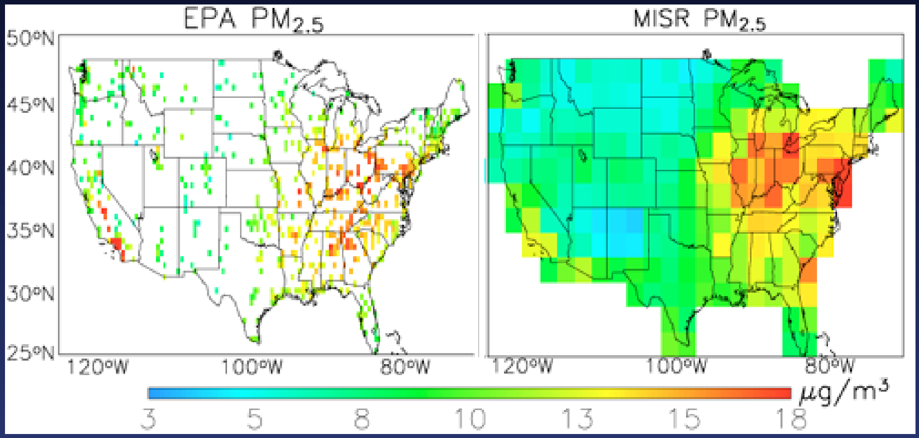
3-backscatter, 2 extinction lidar retrieval	aircraft in situ (r > 50 nm)
r_{eff} = 0.27±0.04	0.25±0.07 µm
n_r = 1.63±0.09	1.56
SSA = 0.81±0.03	0.79±0.02
volume conc. = 13±3	9±5 µm³ cm⁻³

This case study over Germany shows the benefit of a microphysics-capable lidar

Credit: Detlef Müller

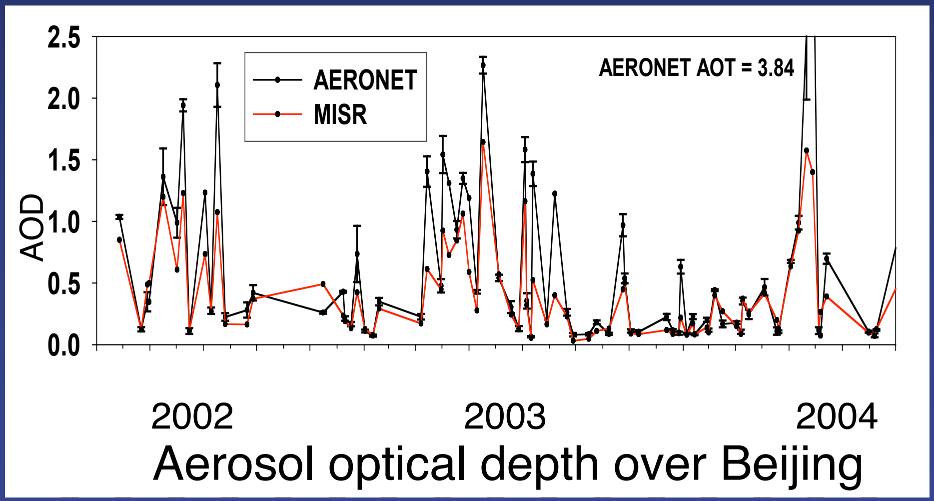
AEGIS contributions to global PM characterization

Example: Mapping particulate pollution



Today: Use of a transport model (GEOS-CHEM) relates MISR column AOD to surface $PM_{2.5}$ yielding good agreement with EPA surface data.

Future: HSRL will provide direct vertical profiles, and the combination of MSPI and HSRL will help sort PM by particle type.



Credit: Yang Liu

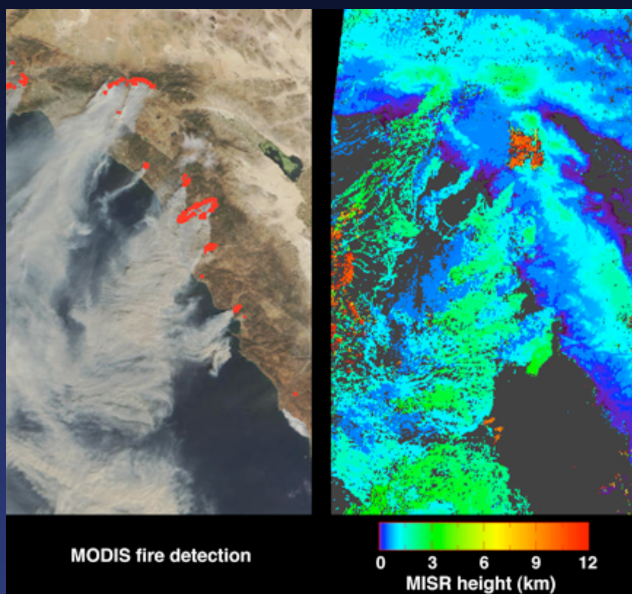
Today: MISR and AERONET optical depths over cities with high particulate levels (e.g., Beijing) are highly correlated;

In this example, MISR underestimates optical depth by 25-30%, most likely due to incorrect single scattering albedo.

Future: MSPI's greater sensitivity to single scattering albedo, coupled with HSRL, will provide much-improved particle models and aerosol type discrimination.

AEGIS contributions to global PM characterization

Example: Tracking aerosol transport in 3-D

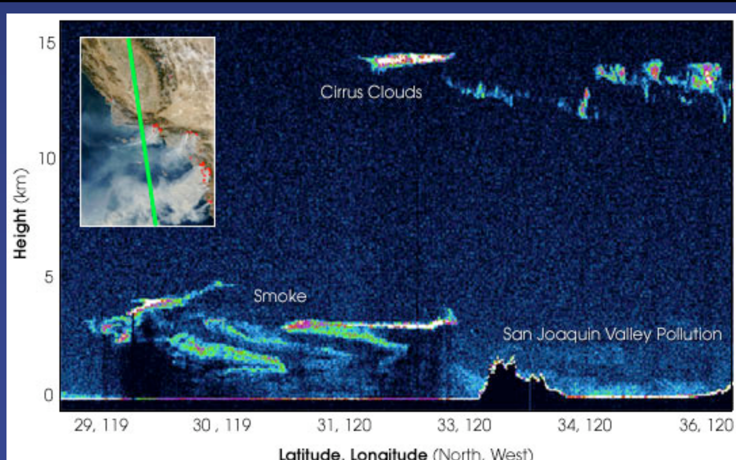


Today: MODIS provides near-daily horizontal coverage of aerosols and identifies active wildfire locations;

Automated MISR stereo retrievals map smoke (and dust) plume top heights;

MISR provides statistical aerosol injection information to calibrate transport models, but current narrow swath misses many events.

Future: MSPI improves upon MISR stereo revisit frequencies by a factor of 2.



Today: GLAS (and in the near future, CALIPSO) lidar provides aerosol vertical layering along subsatellite transects;

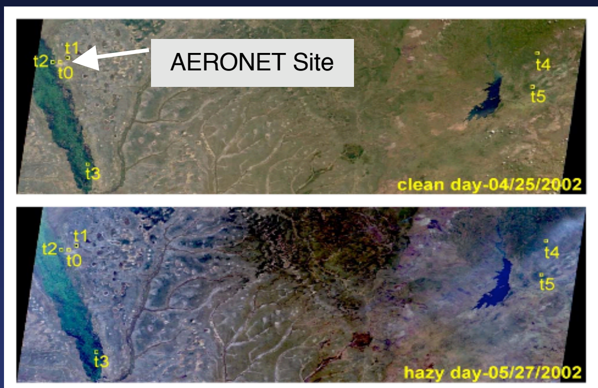
Direct determination of aerosol type in each layer is not possible, and quantitative extinction retrieval requires assumption of particle backscatter-to-extinction ratios.

Future: HSRL overcomes this limitation.

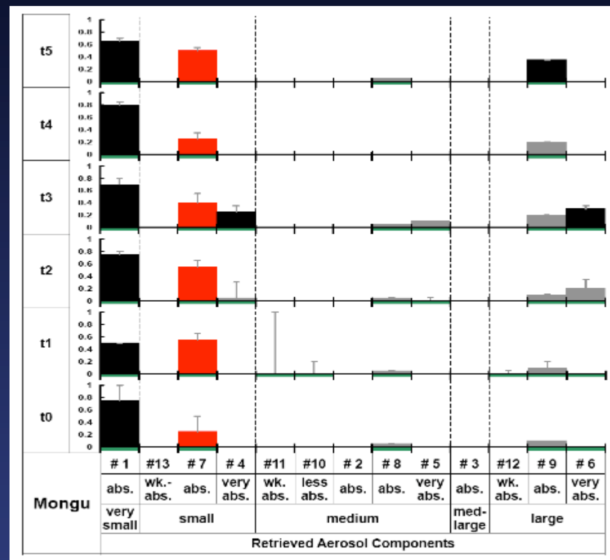
AEGIS contributions to global PM characterization

Example: Identifying particle microphysical characteristics

MISR data over Mongu, Zambia



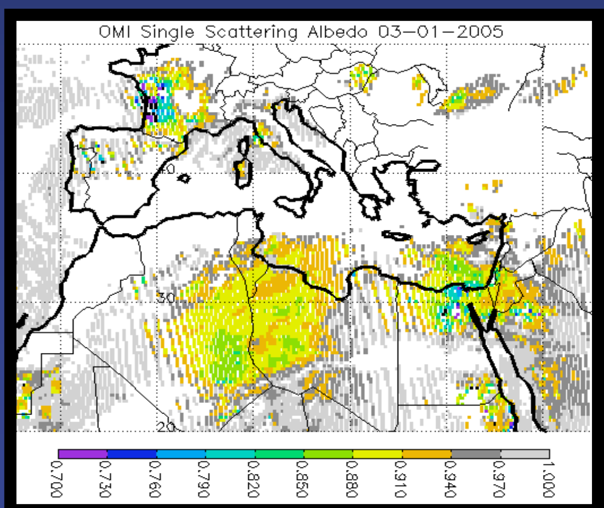
Credit: Wei-Ting Chen



Today: In this case study, MISR analysis retrieves particle sizes and single scattering albedo.

	MISR	AERONET
Size	0.15 - 0.22 μm	0.24 μm
SSA	0.84 - 0.85	0.83
AOD	0.3 - 0.4	0.34

Future: MSPI and HSRL build upon this capability.



Today: TOMS and OMI take advantage of Rayleigh-aerosol interaction and low surface albedo in the near-UV to retrieve single scattering albedo.

Future: MSPI provides near-UV data with high spatial resolution. Multiangle UV imaging could help disentangle effects of optical depth, single scattering albedo, and aerosol height.

Concluding remarks

Particulate pollution has myriad environmental impacts. Quantitative determination of PM distributions, trends, sources, and types is necessary for measuring and predicting exposure and toxicity.

- *In situ* measurements are critically needed, but most source locations are not observed and spatial coverage is limited.

AEGIS incorporates synergistic, advanced-technology passive (MSPI) and active (HSRL) satellite sensors to provide global aerosol coverage, regional context, and 3-D characterization of aerosol amounts and types.

- AEGIS takes major steps beyond EOS, A-Train, Glory, and NPOESS. Its horizontal, vertical, and temporal resolution and coverage will enable aerosol measurements with unprecedented detail, and will facilitate needed integration with surface and *in situ* data.

Along with other instruments (e.g., a cloud side scanner, O_2 A-band spectrometer, cloud profiling radar) AEGIS also addresses objectives relating to aerosol-cloud interactions and climate.

- Sun-synchronous formation flight with EarthCARE is one candidate scenario. After a few years, moving AEGIS to a precessing orbit would provide new information on diurnal variability of aerosols and aerosol-cloud interactions.
- EarthCARE contains a subsatellite single-band (355 nm) HSRL, cloud profiling radar, and broadband radiometer, plus a narrow swath nadir imager.